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Network Externalities in Microcomputer Software:
An Econometric Analysis of the Spreadsheet Market

Abstract

As an economic good, software has a number of interesting properties. In addition to the value of intrinsic features, the creation of or conformance to industry standards may be critical to the success of a product. This research builds and evaluates econometric models to determine which product features are important in the purchase and pricing decisions for microcomputer software. A special emphasis is to identify the effects of standards and network externalities.

Four main results were found for the microcomputer spreadsheet market for the time period 1987-1992.

- Hedonic regression techniques can provide sensible estimates of the value users place on intrinsic features such as the ability to sort the data or to embed charts.
- Network externalities measurably influence the value of products. Each one percent increase in a product's installed base enables the product to command an additional $3.94 in price.
- Purchasers place significant value on adherence to standards. Products compatible with the Lotus menu tree interface earned a premium of approximately 30% of the average price in the sample.
- Shifts in technology platforms substantially change vendor premiums. Products manufactured by Lotus Development Corporation commanded a premium of $272 on the DOS platform, but only $65 on non-DOS platforms.

The results of this research and the general model proposed can be used to estimate the relative values of software package features, adherence to standards, and increased market share. It also quantifies the opportunities created by changes in technology architecture. Finally, the results offer guidance into current public policy issues such as the value of intellectual property embodied in software.

1. INTRODUCTION

The production of packaged computer software is a multi-billion dollar industry in the US alone, and is expected to be among the fastest growing industries over the next decade[1]. In addition, computer software products possess a unique set of economic characteristics. While the fixed development costs tend to be quite high, the reproduction costs are quite low[2]. Furthermore, the purchase price tends to be only a relatively small portion of the total consumer expenditure on software, the remainder coming in the form of learning and conversion costs. This, in turn, creates strong network externalities, with theory suggesting that consumers should prefer to purchase software that is perceived as a standard (Farrell and Saloner 1985; Saloner 1989). Computer software possesses a strong complementary goods relationship with computer hardware, an industry that has experienced significant improvements in its price/performance ratio (Brynjolfsson 1993)

These five factors – the large market, the low marginal cost, the high learning costs, the network externalities, and the complementarity relationship with hardware – provide opportunities for vendors to price their products strategically, taking into account factors such as industry standards, competitor's installed bases, and discontinuities in the hardware market.

The purpose of this research is to build and empirically test an econometric model to identify and measure those factors that are most important in the purchase decision for microcomputer spreadsheet software. It has been estimated that there are already more than 50 million IBM-compatible microcomputers in use, and, with the rapid increases in microprocessor performance and the growing capabilities of networking, this segment is growing at the expense of minicomputers and mainframes (International Data Corporation 1991). Spreadsheets are often credited with fueling the demand for microcomputers, for example, (Cringely 1992, p. 64) calls the first commercial spreadsheet "a compelling application--an application so important that it alone justified the computer purchase."

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[1] *Software Magazine* estimates that the top 100 independent software companies had combined revenues of $13.9 billion in 1991 (Hodges and Melewski 1992, p. 17). An earlier report from *Business Week* set the value at $9 billion in 1989 (Depke *et al.* 1989).

[2] For example, a recent book about the microcomputer software industry claims that typical ongoing margins have been 90% (Cringely 1992).

A special emphasis of the research is to identify the effect of standards on the software adoption process, since they influence both the learning costs and other forms of network externalities. The spreadsheet market makes an excellent test bed for this work since there is a well-identified market standard in this area, Lotus 1-2-3. Lotus 1-2-3 is claimed to be the single most successful computer application ever, and a key ingredient in the success of the highly popular IBM PC (Cringely 1992, p. 147).

Spreadsheets have also been at the center of much recent controversy and discussion. The issue of intellectual property rights in software, and in particular the so-called user interface "look and feel" issue has recently focused on the Lotus 1-2-3 menu tree interface. Lotus Development Corporation has vigorously defended its rights to this *de facto* industry standard in cases with Paperback Software Corporation and Borland International. Assessing the likely market value of this interface can help inform debate on this issue.

Another critical issue is the relationship between application software and its necessary compatibility with a given hardware/operating system platform, or architecture. Morris and Ferguson have recently argued that control over the technology architecture is critical to profitability for vendors in this area, and they specifically claim that Lotus has lost its market dominance due to the shift to non-DOS platforms (Morris and Ferguson 1993). Such examples have fueled discussion over whether Microsoft Corporation, with its activities in both application software and operating system platforms, has an unfair advantage (Rebello *et al.* 1992).

The organization of this paper is as follows. The next section gives a brief overview of previous theory in this area. This is followed by a description of the general model. The third section describes the data used to estimate the model. Results and discussion appear in section 4 and concluding remarks are presented in section 5.

2. RESEARCH MODEL

There is a growing body of largely theoretical literature on the economics of standards and the economics of goods that possess network externalities. One of the contributions of this literature is an explication of the possible consumer *benefits* of standards, such as:

- network externalities from community of users (e.g., ability to share information in a common format)

- market mediation effect (larger market for complementary goods and reduced market power of sellers)
- increased price competition (since competition on other dimensions is reduced and from possible decreases in cost due to production scale economies)
- thicker second hand market, and
- reduction in uncertainty (Stoneman 1987; Westland 1992; Whang 1992).

However, these benefits are balanced by a set of *costs* to standardization:

- reduced product variety or diversity
- "excess inertia" which can slow down movement to better standards
- efficiency loss if wrong standard imposed (David 1985; Farrell and Saloner 1985).

Other important topics in this literature are the role played by compatibility in augmenting or reducing the importance of standards (Gilbert 1992). The existing installed base of a technology affects consumer expectations and compatibility decisions (Farrell and Saloner 1986). Sponsorship of a technology by an industry leader can act to change expectations and/or reduce the importance of a pre-existing installed base (Cusumano *et al.* 1992; Fichman and Kemerer 1993)

Some limitations of this literature are that it is largely theoretical, with little or no empirical validation of the propositions. The models often make a number of simplifying assumptions, (such as constant arrival rates of new users) that may not hold for information technologies such as software. In addition, the economics work tends to adopt a social welfare perspective, with relatively less attention paid to recommendations for strategies for individual consumers or producers in terms of identifying a likely standard, increasing the chances of a product becoming a standard, or taking other effects (e.g. elasticities) into account in establishing a pricing strategy.

Econometric Model

In order to estimate the magnitude of some of the effects of standards, the approach taken here is to estimate a hedonic regression model using annual data on price, and features of a set of microcomputer spreadsheet packages.

This hedonic regression approach, developed in the 1920s, has been used on a wide variety of products and services ranging from asparagus to automobiles to marriage

dowries. A useful history and summary is provided in (Berndt 1991)[3]. Perhaps the first successful application to information technology was for computer hardware in a study done by Chow, who estimated a quality adjusted decline in mainframe computer prices of 21% from 1960-1965 (Chow 1967). Triplett, in a compilation of a set of research in this area, estimated a decline of 27% over the time period 1953-1972 (Triplett 1989). Berndt and Griliches use hedonic regression techniques to estimate the quality adjusted change in prices for microcomputers for the period 1982 - 1988 (Berndt 1991; Berndt and Griliches 1990). They found that the quality adjusted decline in real prices averaged 28% per year over that period.

In order to estimate the optimal strategy for a microcomputer producer, Hartman used a hedonic model, including dummy variables to reflect consumer preferences for such things as more memory, specialized keyboard designs, and whether or not the machine was IBM-compatible (Hartman 1989).

Our work is most closely related to the work of Gandal who uses data from Datapro to construct a hedonic price index for spreadsheet software and estimates that the quality adjusted list prices have fallen approximately 15% for the period 1986-1991. He also finds that Lotus menu compatibility has significant value, which can be interpreted as evidence of network externalities (Gandal 1994) Our results (presented below) are broadly consistent with Gandal's regarding the value of features and the trend in quality adjusted prices over time. However, because our dataset includes data on the installed base of each product, we are able to directly estimate the value of network externalities based on past sales, as well as the value of compatibility with the Lotus menu standard. We are also able to demonstrate that our results hold for a new data set of discount prices, and to test the role of changes in platforms on vendor premiums.

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[3]Hedonic models are designed to estimate that value that different product aspects contribute to a consumers utility, or pleasure (the word "hedonic" stemming from the same root as "hedonism"). According to Berndt, "Implicit in the hedonic price framework is the assumption that ... a particular commodity can be viewed as consisting of various ... bundles ... of a smaller number of characteristics or basic attributes. In brief, the hedonic hypothesis is that heterogeneous goods are aggregations of characteristics. Moreover, implicit marginal prices of the characteristics can be calculated as derivatives of the hedonic price equation with respect to levels of the characteristics." (Berndt 1991, p. 117)

The general model for this research is:

(1) $P_{it} = f(H_{it}, N_{it}, T_t)$

where: P_{it} = Price of software package i (in year t)
H_{it} = Vector of quality attributes " " " "
N_{it} = Network Externalities " " " "
T_t = Time dummies

The expected signs on the time dummy variables are negative, reflecting a decline in price over time, whereas the other variables would be expected to be positive. The approach taken is to take the general model developed above, customize it to accommodate the appropriate hedonic variables for the microcomputer spreadsheet package market, and to then estimate the model.

3. DATA

Given the model above, two kinds of data are needed, market data on the price and unit sales of various products by year, and attribute data on which features were provided by each product. The data used in this study overlap significantly with data originally compiled by MIT students Donna Mayo and Daniel Young and described in (Mayo and Young, 1993).

List Price and Unit Sales data

It was critical to obtain reliable information on product pricing. DataQuest and International Data Corporation (IDC) both very generously provided data on the spreadsheet market. These two market analysis firms are the leading data sources for information on the software industry (Rebello *et al.* 1992). Market coverage for the IDC and DataQuest data set covers the 1987 to 1991 period. DataQuest provided market data for a broader range of products in almost every year. Product list prices for 1992 were collected from trade press reviews. As a result, the sample may under represent the number of different products actually sold during 1992. The data were organized as a pooled cross-section of up to 22 unique products in each of six years. The total data set consists of 93 observations.

Since these data include a time series component, the nominal prices require adjustment to account for inflation. Product prices were deflated to 1987 dollars using the GDP deflator. Therefore, the dependent variable is real, rather than nominal, price. We computed the installed base of each product in each year by summing its sales in all prior years, including sales of earlier, compatible versions. The installed base *share*, in turn, was computed by dividing the installed base of each product by the sum of the installed bases for all products.

Discount price data

The IDC and DataQuest data reflect a package's list price. This is consistent with hedonic pricing models used in computer hardware studies, e.g. (Cole *et al.* 1986). However, because much microcomputer software is sold at a discount from list price using list price data to develop the hedonic model may introduce bias if discounts across products are systematically related to the explanatory variables in the model. In order to check whether such a bias existed, a third, independent set of price data was constructed from the prices of the software packages as advertised in major microcomputer trade magazine advertisements. Discount prices were found for a subset of 55 of the 93 observations in the full sample. The average discount was found to be 30.5% off list price and a correlation of .88 was found between discount and list prices.

Attribute data

There were two goals for selecting a primary source for the product attribute data. First, a single source that contained consistent and comprehensive information on product features was preferred. Second, it was desirable to include products for the Macintosh. Apple computers now comprise over 12 percent of the installed base of personal computers (Standard and Poors Corporation 1991).

A review of the comparative spreadsheet product reviews offered in major computer trade journals quickly revealed that the features reported on varied somewhat from year to year. Further, the set of products reviewed in any given year is often limited to only the most popular programs. Thus, it was not possible to rely on reviews from any one of these journals entirely.

One source that did meet the goals of the research was National Software Testing Lab's (NSTL) *Software Digest Ratings Reports* (National Software Testing Laboratories 1985). NSTL began publishing in 1984 and produced at least one and sometimes two issues dedicated to evaluating spreadsheet products in each year. Most of the products covered are business-class spreadsheets. Beginning in 1988, NSTL began publishing a set of reports dedicated to Macintosh products thus allowing the inclusion of most of the more significant Macintosh products in the product set (National Software Testing Laboratories 1988a; National Software Testing Laboratories 1988b),

Each NSTL report also contains detailed definitions of the product features. These definitions allowed the confirmation that the feature information collected was

truly comparable across years for different products, which further increased the confidence in this source. The sample set covers products sold for the years 1987 through 1992.

For the sake of thoroughness, these data were also supplemented and cross-checked with spreadsheet review articles from *PC Magazine, InfoWorld, Byte, Computerworld* and others[4]. For instance, all articles on spreadsheet products since *PC Magazine*'s inception in 1982 were examined. The data were also checked against product manuals when available for the more recent products.

Given these data sources, a considerable task remained, which was the selection of those features deemed most likely to be important to be included as independent variables in the model. Fortunately, the view of the independent experts in the software reviews was quite consistent in these decisions for spreadsheet software. The large number of possible dimensions are best represented by three broad traits, as evidenced by the following quote:

> *"When choosing a spreadsheet, users still need to find a program with the capacity to handle the required quantity of data, the features to manipulate the data into the required formats, and the ability to output the data in an attractive easily read presentation.* (National Software Testing Laboratories 1989, p. 3)

Within these three categories it seems clear that there are a relatively large number of possible features that could be used to represent them. However, in terms of the model, inclusion of more than a very small number would result in collinearity. Therefore, selection of representative variables was necessary. These variables were chosen based upon the importance placed upon them in contemporaneous reviews.

A data manipulation variable is the ability to *sort by columns*. According to contemporary industry sources, the ability to sort by columns is a sophisticated measure of data manipulation:

> *Sorting the data can quickly clarify the structure of a confusing worksheet. All of the programs can sort by rows; only [several programs] offer the option of sorting by columns* (National Software Testing Labs 1988, p. 6).

A product's ability to do *"cell linking"* by using a cell reference from an external worksheet in a formula in the current worksheet, is a clear aid to modeling as reported in NSTL's 1988 report on spreadsheets:

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[4]A complete listing of these additional sources is provided in (Mayo and Young 1993)

> *Many of the useful functions of three-dimensional worksheets can be simulated in a two-dimensional environment through the use of links...Vendors who hope to maintain the viability of their products will have to scramble to offer linking in future versions* (National Software Testing Labs 1988 pp. 7-8).

An output related variable is whether or not the spreadsheet offers a What You See Is What You Get (*WYSIWYG*) interface. This has become increasingly common over the time period studied. Finally, the ability to *embed charts* has become an important output-related capability that is often featured in product advertisements. It is a relatively sophisticated output variable as only 45% of products in the total dataset can embed charts on the worksheet.

Network externalities

Application software exhibits positive network externalities in that the value of a product to an individual user increases to the degree that other people also use it (Arthur 1988). The classic example of a product that exhibits network externalities is the telephone, whereby having telephone service is only valuable if there are other people with compatible telephones that a user wishes to call. A more modern example might be electronic mail systems, where they are most valuable to the degree that many other people in the organization actually use them. The application of this idea to software is that users will prefer more popular (widely sold) spreadsheets to less popular ones, *ceteris paribus*. They will receive benefits such as the greater presence of third party training opportunities and materials, of complementary or compatible products, of user groups, and of greater likelihood of vendor viability. Therefore, it would be expected that products with larger *installed bases* will exhibit a price premium over products with smaller installed bases (Farrell and Saloner 1986).

Given Lotus's dominant market position, there should also be an advantage, in the form of network externalities, to being *Lotus-compatible*. Since Lotus 1-2-3 has been the dominant product in the market since its introduction in 1983, many products have attempted to capitalize on the knowledge of Lotus' installed user base by providing the option to use, for example, an exact duplicate of the Lotus 1-2-3 menu tree or a menu tree that operates in the same manner. It was this copying of the menu tree that was at the heart of the lawsuit between Lotus Development Corporation and Paperback Software International, which further indicates the

perceived value of this particular standard[5]. Part of the value of the Lotus 1-2-3 menu tree stems from the greater ease of use for the installed base of users who already know the Lotus menu tree and the consequent reduction in learning costs, as witnessed by these quotes from contemporary software reviews:

> *Slash-F-R to retrieve a file. Slash-F-S to save. Slash-W-E-Y to clear the worksheet. Slash-C, mark the source range, mark the destination. Countless spreadsheet users are familiar with the command sequences popularized by Lotus 1-2-3... Because many of these users are familiar with 1-2-3, the ideal program is one that uses the same command sequence* (National Software Testing Labs 1990, p. 7)

> *Quattro gives users the choice of selecting any of several optional interfaces. In general, our testers liked the Lotus-style screen and menus, rating 1-2-3 and the five "clone" programs highly for both ease of learning and ease of use* (National Software Testing Labs 1988, pp. 4-5).

Therefore, a standards effect is represented by a Lotus Menu dummy variable[6]. The Lotus Menu variable also represents the highest switching cost for the large population of Lotus 1-2-3 users[7].

Make effect

In addition to the specific network externality benefit of the Lotus menu tree structure, there may be other benefits that are ascribed by consumers to Lotus products. Given Lotus's early and dominant market position, they have been seen as a market leader during this period. Therefore, their long term viability was unlikely to be a problem, and a consumer making a purchase decision could assume that ongoing vendor support would be assured. In addition, continued improvements to the product in the form of new releases could be expected. Finally, the Lotus brand name may act as a proxy for a general product quality

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[5]Lotus Development Corp. v. Paperback Software International, 740 F. Supp. 37 (D. Mass. 1990).

[6]Of course, another part of the value may be due to an intrinsically well-designed interface. Thus, the Lotus menu tree is an imperfect measure of the value of standards and network externalities and needs to be interpreted cautiously as a result.

[7]An alternative variable could have been the ability to read and write Lotus-compatible files. The Lotus menu interface was selected instead, since it was felt that this presented a stronger form of the network externality in that a switch by an organization to another product would require an investment by every user in re-training, whereas incompatibility in reading and/or writing files could be solved through a one-time construction or purchase of a converter (Farrell and Saloner 1992; Matutes and Regibeau 1988)

variable. Collectively, these effects are captured as a "make effect" by the Lotus manufacturer dummy variable (Berndt 1991).

Descriptive statistics

The data sample was confined to spreadsheet products designed to be sold commercially, rather than distributed via the "shareware" method[8]. Also excluded were spreadsheet-like products geared mainly towards specialized financial modeling applications, such as Javelin and Encore. Although some of these products are capable of the operations typically performed with traditional spreadsheets, financial modeling tools are targeted to a different group of users. As one reviewer wrote:

> *Financial-modeling products are not in direct competition with [Lotus] 1-2-3, but rather serve a need that's well beyond the capabilities of general-purpose software. They offer a broad variety of capabilities and features, so that even power users learn only a fraction of the system's capabilities* (Moskowitz 1988).

Finally, to allow the assessment of the price and demand relationships more accurately, the data set includes only standalone spreadsheet programs, not spreadsheets sold as part of an integrated package[9]. It is infeasible to determine the spreadsheet module's portion of the price of an integrated software package.

This dataset consists of consistent information for products that represent at least 75% of units sold in each year 1987 to 1991 according to DataQuest and IDC. This is felt to offer broad coverage of the spreadsheet market for products available for different computer platforms and operating systems during this period. With these multiple years of data both longitudinal and cross-sectional differences can be observed. Two independent sources were used for the list price data. These were found to be relatively consistent with each other, as well as highly correlated with the discount price data.

In total, the dataset contains 93 different product observations, where a new observation is generated for each spreadsheet revision and each year that the

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[8]When software vendors release a product as shareware, they give permission for the program to be copied freely. However, they request that if the user finds that the program fits his needs that he send payment for the product. Shareware products are aimed primarily at home or casual users and often do not include many features that are taken for granted in the other more sophisticated products, such as complete manuals, customer support, etc.

[9]Integrated software packages generally include a word processor, a spreadsheet, a communications package, and other modules all in one box for one price.

revision is offered. It is worthwhile to note that despite the fact that a new version of a product may enter the market, sales of older versions continue. Practically, this results because new products are not neatly introduced at the start of a year, nor are older products withdrawn at a year's close. Also, there are users who choose to continue purchasing a perhaps out-of-date version of a product to maintain guaranteed compatibility with current files and applications or to avoid the necessity to upgrade their hardware which is sometimes a requirement of new software releases. This notion proved to be especially relevant for Lotus 1-2-3 products where, for example, sales of Lotus 1-2-3 Release 2.01 continued through 1991 despite its initial release being in 1985. Taking into account repetition of prior products, there are 22 distinct products (such as Lotus 1-2-3 versus Microsoft Excel) and 68 distinct versions of products (such as Lotus 1-2-3 ver. 2.2 versus Lotus 1-2-3 ver. 3.0) in the data sample. Table 1 below shows the distribution of the product set by year.

Table 1: Distribution of Sample By Year

Year	Number of Data Points
1987	11
1988	15
1989	17
1990	19
1991	22
1992	9
TOTAL	93

The data set covers spreadsheets made by 11 vendors. The following table details how many data observations are attributable to products from the three major spreadsheet vendors.

Table 2: Distribution of Sample By Vendor

Vendor	Total Data Points
Lotus	23
Microsoft	21
Borland	9
Others	40
TOTAL	93

This data set includes 58 data observations for products that operate under MS-DOS on PC-compatible computer platforms and 35 data observations that run under graphical operating systems (MS-Windows, OS/2, and Macintosh) on Apple Macintosh or PC-compatible computers. The following table shows the distribution of the data set over these four operating systems.

Table 3: Distribution of Data Set By Operating System

Operating System	Data Points
MS-DOS	58
Macintosh	17
Windows	12
OS/2	6
TOTAL	93

Figure 1 below shows the distribution of the five attribute variables over the six years covered by the dataset. Some features, like cell linking (CELLINKF), embedded charts (EMBEDCHT) and a WYSIWYG user interface (WYSIWYG) grow significantly in availability over the time period of the sample. Table 4 provides summary statistics for the dataset.

Figure 1: Percentage of Products With Feature By Year

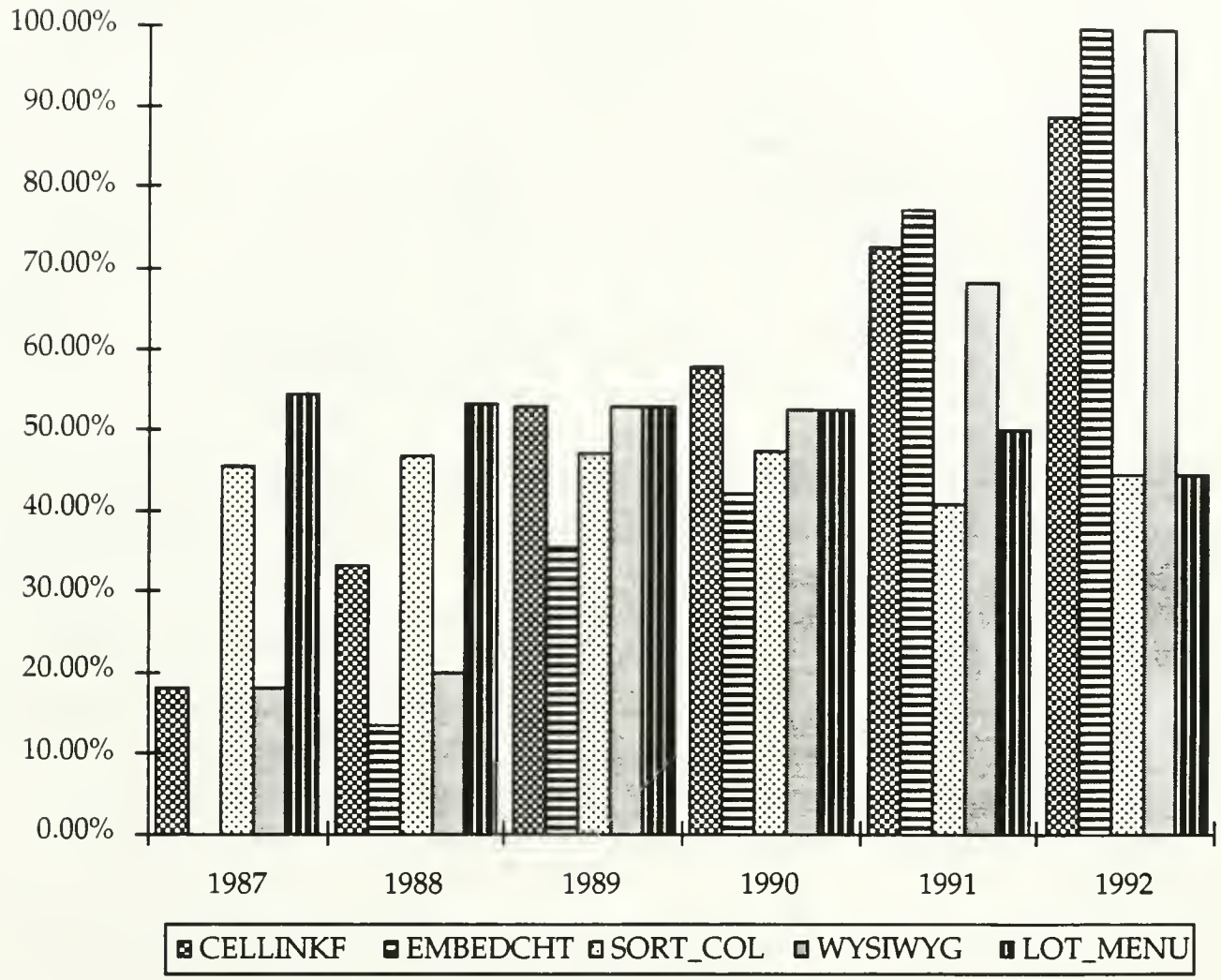

Table 4: Descriptive Statistics

Variable	n	Mean	s.d.	Maximum	Minimum
R_LIST_P	93	338.362	135.462	615.73	59.85
CELLINKF	93	0.548	0.500	1.00	0.00
EMBEDCHT	93	0.452	0.500	1.00	0.00
LOT_MENU	93	0.516	0.502	1.00	0.00
SORT_COL	93	0.452	0.500	1.00	0.00
WYSIWYG	93	0.516	0.502	1.00	0.00
BASESHAR	93	6.451	12.268	64.65	0.00

There are several product attributes for which information was not readily available. For instance, while a spreadsheet's speed (e.g., file loading speed,

recalculation speed, etc.) may enter into a buyer's purchase decision, obtaining comparable estimates of speed for many products is infeasible for a number of reasons. From the NSTL reports, speed ratings are available for only a small fraction of the data sample. The issue of product speed is further muddied by the fact that advances in microcomputer processor speed throughout the period under consideration make speed rates from year to year incomparable. Furthermore, it may also be true that speed of spreadsheet operations is becoming a secondary issue simply because hardware advances can be counted upon to make up for deficiencies of the software itself, e.g.:

> *To be sure, in this era of affordable 386-based machines, recalculation speed is a minor point compared with time spent constructing spreadsheets and preparing output to communicate their results* (Coffee 1991).

It may have been interesting to investigate product ratings for ease of use or learning, or other more subjective product qualities. However, such qualitative ratings from a consistent source are available for only a fraction of the data sample. In addition, more objective measures of product features may proxy for more nebulous concepts like ease of use or learning. For instance, products that offer the Lotus menu interface are often heralded for their ease of use. By quantifying the value of this interface, it may be possible to gain insight into the value-added created by producing a spreadsheet product that is easier to use than others in the marketplace. In addition, vendor reputation may subsume some less tangible factors.

Another concern may be that other factors, such as competitive pressures, hardware innovations, and other market factors may also have an impact on spreadsheet software prices. It is believed that the time dummy variables may control some of these effects, with the rest being captured by the error term.

Finally, all such estimations are limited by the fact that the data may be measured with error. This has been minimized in this study through the use of contemporaneous industry standard sources.

4. RESULTS

Using ordinary least squares regression techniques, the following general equation is proposed:

(2) $P = \beta_0 + \beta_i * \text{Attribute i} + \beta_j * \text{Network Externality j} + \beta_k * \text{Year k} + \varepsilon$

The hedonic model was estimated using both the pure linear and semi-log form of the regression equation. The difference between these two approaches is that the pure linear form expresses the dependent variable, product price, in dollars, while in the semi-log form the dependent variable is the natural log of product price. The choice of functional form does not effect any of the dummy variables. A slightly better fit, as measured by a higher value for the adjusted R^2 of the regression, was obtained using the linear form. The linear form was also preferred to the semi-log as the coefficients obtained from the regression can be interpreted directly as the value-added associated with a given product characteristic. Therefore, the results in this section are reported using the linear equation form. In either form, the main results of the model are similar.

The specific equation is as follows:

(3) $\mathbf{R\_LIST\_P = \beta_0 + \beta_1 * CELLINKF + \beta_2 * EMBEDCHT + \beta_3 * SORT\_COL + \beta_4 * WYSIWYG + \beta_5 * BASESHAR + \beta_6 * LOT\_MENU + \beta_7 * T88 + \beta_8 * T89 + \beta_9 * T90 + \beta_{10} * T91 + \beta_{11} * T92 + \varepsilon}$

Description of the Base Case Product

The base case product, for which all the dummy variables were set equal to zero, is a business-level spreadsheet sold in 1987 that

- cannot link external worksheets in formulas in the current worksheet,
- cannot embed charts on the worksheet,
- cannot sort data by column
- does not have a WYSIWYG interface
- has no installed base of users, and
- does not have a Lotus 1-2-3 style menu tree.

Table 5 below presents the results of the model. The signs of all the attribute variables were as predicted and were significant at least the 95% level of confidence. To guard against possible heteroskedasticity in the sample, all standard errors and confidence levels were calculated using a heteroskedasticity consistent covariance matrix.

Table 5: Results of the Hedonic Price Equation Estimation
List Price (in 1987 Dollars) is the Dependent Variable

VARIABLE	COEFFICIENT	T-STAT	2-TAIL SIG
C	113.419	2.562	0.013
CELLINKF	82.050	2.395	0.019
EMBEDCHT	93.102	2.339	0.022
SORT_COL	91.715	2.841	0.006
WYSIWYG	79.364	2.604	0.011
BASESHAR	3.941	5.028	0.000
LOT_MENU	115.173	4.507	0.000
T88	17.077	0.385	0.701
T89	0.610	0.013	0.989
T90	-24.483	-0.544	0.588
T91	-77.695	-1.591	0.116
T92	-95.243	-1.705	0.093
N	93		
S.E. of Regression	96.550		
R^2	0.553		
Adjusted R^2	0.492		

The constant term estimated in the regression may be interpreted as the price of the base case product in 1987, including associated margins. The results for the smaller subset of 55 discount price data observations are very similar, and are presented in Appendix B. A Chow-test was run of the null hypothesis that the coefficients (except for the constant term) were identical for list price and discount price. This test was unable to reject the null hypothesis ($F(12,86)=.391$, 5% value = 1.92). Therefore, in the discussion that follows only the results from the full (list price) model will be analyzed[10].

The time dummy variables (T88-T92) reflect a pattern of decline over the period studied. These may be interpreted as the price decrease in each year, holding the other quality factors constant. Over the entire period, the results imply that quality-adjusted price declined in real terms by an average of approximately 6.4% per year,

[10]It is interesting to note that Berndt and Griliches also do not reject the notion of parameter equality (aside from a parallel shift) in the list and discount datasets in perhaps the only previous hedonic study of information technology that uses a combined dataset of both list and discount observations, (72% of their hardware price observations were from list price data) (Berndt and Griliches 1990) .

which is in contrast to the relative stability of the nominal price in these products over this period[11].

Interpretation of the four basic product attribute (feature) variables is straightforward given that a linear model is used. The ability to perform cell linking within a formula (CELLINKF) is estimated to add $82.05 to the price of a product that has it, versus one that does not, *ceteris paribus*. Similarly, the ability to embed charts in a spreadsheet (EMBEDCHT) is worth $95.10, sort by columns (SORT_COL), $91.71, and the WYSIWYG feature, $78.36. The main network externality effect is represented by a product's share of the installed base of spreadsheets (BASESHAR). Each percentage point of share has an estimated value of $3.94. Therefore, a widely sold product that had, for example, 50% of the market would earn an estimated premium of $197.00 (3.94*50).

The LOT_MENU variable represents the effect of the dominant user-interface standard. The estimated value is $115.17, a significant portion of the price of a typical spreadsheet, and a larger estimated coefficient than any of the other four basic product feature coefficients.

Estimation of this value provides useful insight into an issue of current concern, namely, appropriate financial damages amounts in cases involving other firms' usage of Lotus Development Corporation's Lotus 1-2-3 menu tree. A court has recently ruled that Borland infringed on Lotus's copyright, and, if this ruling stands, a decision will have to be made as to what the damages should be. Multiplying the estimated value of $115.17 by the unit sales data from 1987-1991 of Borland products that possess the Lotus menu tree interface provides an estimated value of approximately $233 million[12]. This number may be an overestimate to the extent that it is based on list price, not discount or wholesale price. In addition, it is not obvious that all of this revenue would otherwise have accrued to Lotus. On the other hand, the figure of $233 million underestimates the damages to the degree

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[11] An alternative, less general form of the model would be to include only a single time trend dummy variable, incrementing its value by one for each year beyond 1987. This form conserves degrees of freedom, but is less general since it forces the value of the time dummy to be equal for each of the years. The results of this restricted form model gave an estimated value for the time dummy of -22.67 (t-stat =-2.627), which is consistent with a decline in price over time of 6.7% per year. All of the other values in the model remained essentially unchanged. An F-test of the two models did not reject the null hypothesis of a linear time trend (F(4,81)=.687, 5% value = 2.53).

[12] For comparison, *Computerworld* reports that Lotus will seek damages of $100 million (Vizard 1993).

that there were Borland products prior to 1987 or after 1992 that were sold that included the interface. Therefore, further data and analysis could be used to refine the $233 million estimate.

Comparison of Actual and Predicted Product Price

In Table 6 below, the base case model is applied to an illustrative range of products selected to represent various platforms and price points from 1990. As the table indicates, the model does a good job of explaining the observed prices for products in the spreadsheet market, especially for those products that operate on the DOS operating system. To arrive at the predicted list prices of a given product, sum the regression constant of $113.41 and the time coefficient of ($24.48) for 1990 with the values associated with the attributes present in the product. For example, the regression model predicts the price of the first product listed in Table 7, Excel for Windows, as earning positive amounts of $113.41 from the constant term less ($24.48) for the 1990 spreadsheet market, $8.53 for its percentage of the installed base, $82.05 for its cell linking ability, $78.36 for its WYSIWYG interface, an $91.71 for its ability to sort data by column. The sum of $349.58 is almost exactly the actual price of $349.95. Negative errors (ACTUAL — PREDICTED) can be interpreted to mean that the product offered slightly more features per dollar of price, i.e., an attractive features/price ratio. Similarly, positive errors can be interpreted to mean that the product may have been overpriced relative to other products in the market.

Table 6: Model Predictions for Selected 1990 Products (Base =$88.93 (=$113.41-$24.48))

Product (Platform)	Base = Constant-1990 dummy value	Baseshar value	Lotmenu value	Cellinkf value	Wysiwyg value	Embedcht value	Sortcol value	Predicted Real List Price	Actual Real List Price
Excel-(WIN)	88.93	8.53	0	82.05	78.36	0	91.71	349.58	349.95
Quattro Pro (DOS)	88.93	5.29	115.49	82.05	78.36	93.84	0	465.22	438.54
Lotus 1-2-3 Ver. 3.0 (DOS)	88.93	86.39	115.49	82.05	0	93.84	0	467.96	527.13
MultiPlan (DOS)	88.93	13.70	0	0	0	0	91.71	194.34	172.76
Wingz-(MAC)	88.93	0.67	0	82.05	78.36	93.84	0	345.11	442.08

Make effect

Because Lotus is the vendor with the dominant market position, an alternative version of the model was tested adding the dummy variable equal to one if "manufacturer = Lotus Development Corporation", and zero otherwise (MFR_LOT). The addition of this variable is marginally significant (α = .07, two-tailed test), with an estimated coefficient of $68.09. There is collinearity between MFR_LOT and BASESHAR, as the value of BASESHAR changes to $2.80, although it remains statistically significant. The value of LOT_MENU changes also, but less dramatically, reflecting the fact that while there is some correlation between the variables, it is less than that between MFR_LOT and the installed base. The other feature variables and the three time dummies are not significantly affected. One interpretation of the MFR_LOT variable is that it represents the premium paid for the Lotus brand name, independent of the installed base effect (BASESHAR) and the Lotus menu standard effect (LOT_MENU). In other words, this model would provide an estimate of about $68 of the price of Lotus brand products ascribed to be a "make effect" (Berndt 1991).

In terms of the entire model, despite the improvement in R^2, an F-test of the unrestricted model including the MFR_LOT variable does not allow rejection of the original restricted model at the 5% level (F-value of 2.96, critical value of 3.92).

Change in Technology Architecture

An issue of increasing importance in technology systems is a product's compatibility with complementary product standards. In the case of packaged software, these applications must be compatible with an existing technology architecture, or platform, consisting of computer hardware and operating systems.

Compatibility with complementary technologies is considered to be an important determinant of the likelihood of a product's success, and therefore a change in the complementary technology offers an opportunity for new entrants (Farrell and Saloner 1987). Recently, several authors have suggested that such shifts occur in the microcomputer software market; for example, Cringely notes the opportunity for Lotus 1-2-3 that was created by the development of the IBM PC/DOS platform as an alternative to the Apple II platform where the Lotus 1-2-3 predecessor, VisiCalc, was already established (Cringely 1992). Morris and Ferguson suggest that a similar change is taking place as the IBM PC /DOS platform that is Lotus 1-2-3's home is replaced by graphically oriented "architectures" centered on Windows which

provide an opportunity for Microsoft's Excel product to become dominant (Morris and Ferguson 1993).

In order to test these ideas the dataset was split into two subsets, one consisting of products operating under the older, dominant operating systems, DOS (n=58), and the other consisting of the non-DOS (i.e. Mac, Windows, and OS/2) products (n = 35). The small size and the specific nature of the non-DOS sample necessitated some modifications to the model in order to permit estimation of the parameters. Specifically, there was no variation in the dummy variables WYSIWYG and CELLINKF (all valued at "1") in the non-DOS sample and they had to be dropped. Similarly, the variable LOT_MENU was not included because it was perfectly collinear with MFR_LOT in the non-DOS sample. Finally, the small size of the dataset required a parsimonious model, and since MFR_LOT, MFR_MS and MFR_BORL were already to be included, BASESHAR, which is correlated with the vendor dummies, was dropped. For comparison, the limited model run against the full dataset and the values for the vendor dummies are presented in Table 7[13]. Of the vendor dummies, only MFR_LOT is statistically significant, with an estimated value of $177.28. This presumably reflects some value for its installed base share as well as any residual make effects.

Table 7: Partial Results of Technology Architecture Regression, Full data-set (n=93)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
MFR_LOT	177.28	6.778	0.000
MFR_BORL	54.92	1.191	0.238
MFR_MS	35.84	1.127	0.263

The identical model was run using both the DOS-only sample and the non-DOS sample, the results for the vendor dummies are shown in Tables 8 and 9 below.

Table 8: Partial Results of Technology Architecture Regression, DOS data-set (n=58)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
MFR_LOT	272.48	5.987	0.000
MFR_BORL	122.84	1.937	0.059
MFR_MS	-42.21	-1.149	0.257

[13]In this model the remaining feature variables, EMBEDCHT and SORT_COL, remain positive and significant.

Table 9: Partial Results of Technology Architecture Regression, Non-DOS data-set (n=35)

VARIABLE	*COEFFICIENT*	*T-STAT*	*2-TAIL SIG*
MFR_LOT	65.28	4.954	0.000
MFR_BORL	46.89	3.409	0.002
MFR_MS	119.998	5.735	0.000

In the DOS sample, the MFR_LOT premium increases to $272.48, and MFR_BORL becomes marginally significant at $122.84. MFR_MS is not statistically different from zero. However, in the non-DOS sample (Table 9), the MFR_LOT and MFR_BORL premiums are only $65.28 and $46.89 respectively, while the MFR_MS premium is $120.00.

Based upon analysis of the subsets of the data, the Lotus premium is more than 4 times greater on the DOS platform than in the newer environments. In contrast, on the new platforms, Microsoft has become the premium spreadsheet vendor. These results are consistent with the Morris and Ferguson argument that the movement away from DOS created an opportunity for Lotus's competitors, and that Lotus failed to protect their dominant position in the marketplace.

Discussion and Future Research

The analysis above demonstrates that demand for packaged software can sensibly be modeled as a function of the features of that software, and that such a model can indicate the likely magnitudes of the effects of these features. In particular, this model of spreadsheet software has shown that the positive network externality effects from installed base and from compatibility with a dominant standard is at least as important as many previously documented traditional product features, and that manufacturer make effects also play an important role. These results provide additional empirical data for the ongoing economic study of innovations and compatibility.

These specific results also have a number of practical implications. For software vendors they offer insights into appropriate package offerings. Developers can see the marginal value attributable to either features previously provided or currently provided by other vendors in order to glean insights about relative consumer preferences. Marketing staff can infer lessons about the relative rate of change and therefore likely duration of existing market premiums. Legal staffs can use these results to estimate, for example, the market value of compatibility with an existing standard for licensing purposes or for the estimated damages amount in lawsuit claims.

Another aspect of the results is the change in quality-adjusted prices over time. Despite popular conceptions about software performance stagnation, the prices of spreadsheet software, adjusted for features, have declined significantly over time. In contrast to the notion that software development has not progressed, consumers are receiving significantly more sophisticated products at the same cost.

In addition, what is interesting is not only the general overall decline in quality-adjusted price, but the changing value associated with the vendor premium. These changes in value appear to be related to changes in complementary goods, specifically the hardware and operating system platforms that the application software requires to run. From these examples and the data in the current study of spreadsheet software it seems clear that entry into the software market is more likely to be successful when there is a major change in platform. Inertia due to network benefits is hard to overcome when many users are locked-in to an existing platform. However, when there is a significant change in the environment, this may tip the balance and make users willing to abandon their previous application software. Farrell and Saloner model a constant arrival rate of new customers and speculate that a non-constant arrival rate will lead to more entry during high growth periods (Farrell and Saloner 1986). Another way to look at it is that a new hardware or operating system platform "levels the playing field" and erases the advantage of the incumbent network. This complementarity with hardware shows up in other ways, for example, Microsoft surpassing Computer Associates as the largest software firm is undoubtedly a function of the large scale shift to microcomputers from minis and mainframes. The results of the current study of spreadsheet software document and quantify this type of effect.

Given that the data suggest that the premium spreadsheet vendor in the new environment is Microsoft Corporation, this has raised some concern over their simultaneous control over one of the major new operating systems platforms, Windows (Rebello *et al.* 1992). Much concern has been raised about Microsoft's possible monopoly control over the industry, and more than one Federal government investigation has been launched. Interestingly, economic theory suggests that, at least under certain conditions, having a vendor able to offer both complementary products may be advantageous to consumers. For example, Church and Gandal model incentives for integration into software by each of two hardware [platform] producers (Church and Gandal 1992). Applying this model to a vendor such as Microsoft or Apple would actually suggest that because they provide both

application and systems software, they have incentives to keep prices lower (internalizing some of the externality of the increased demand this generates). Essentially the argument is that by lowering the price of, for example, the operating system, this not only generates increased sales of that item (assuming elastic demand), but also generates some additional sales of the compatible application software, as the total system price of both components has been reduced.

A future direction for this research is suggested by Milgrom and Roberts who model highly complementary factors of production and show that "all or nothing" outcomes are generally optimal (Milgrom and Roberts 1990). If it is found that success rates are markedly better for entrants at certain opportune times, it would obviously be of great interest to the business community. Implications for government policy also could be drawn from such findings.

Other, shorter term future research would involve adapting the model developed here to other categories of microcomputer software. For example, word processing software has had a number of important vendors and products (WordStar, WordPerfect, Microsoft Word), as opposed to the historical near-monopoly position of Lotus in the business spreadsheet market. In the database market, Ashton-Tate's early dominance with dBase has lessened without a single dominant newcomer. It might be expected that results for these markets would differ from spreadsheets.

In addition, with such data on other categories it would be possible to develop a richer model of a greater portion of the total microcomputer software market, by estimating a system of simultaneous equations which would allow for various cross-equation restrictions. For example, vendors with products in multiple categories could be expected to benefit from this breadth of offering through a stronger make effect. This make effect variable could be restricted to be equal across equations if that was felt to appropriately represent the realities of the market. Alternatively, the degree to which reputations varied across product categories could be tested. Similarly, compatibility effects may also differ in, for example, the case where no single standard dominates.

5. CONCLUDING REMARKS

Four main results from a hedonic regression model were estimated for the microcomputer spreadsheet market for the time period 1987-1992.

- Analysis of software prices can be used to estimate the value users place on features. This includes features such as the ability to sort the spreadsheet by columns and the ability to embed charts on the spreadsheet.

- Compatibility can be more important than features. In addition to the intrinsic capabilities of the product, purchasers were found to place significant value on its adherence to standards, as shown by an estimated value of $115 on a product's compatibility with the Lotus menu tree interface.

- Due to likely network externality effects, products with a significant installed base command a premium price. It is estimated that ownership of each percentage point of the total spreadsheet software installed base was worth an additional $3.94 to the price of each unit sold.

- Shifts in technology platforms substantially change compatibility and vendor premiums. Products manufactured by Lotus Development Corporation commanded a premium of $272 on the DOS platform, but only $65 on non-DOS platforms.

The contributions of the research, in addition to a greater understanding of the packaged software industry, may also lead to suggestions on policy implications for the US software industry.

APPENDIX A:

As noted earlier, the feature variables were selected because they were believed to represent important product attributes. One test of the quality of a hedonic regression such as is estimated in Table 5 above is whether it passes the specification test proposed by Berndt and Griliches (1990). They argue that any quality change that is not captured by the selected attribute variables should be unrelated to the "vintage" of the product, i.e. the first year the product was available. Essentially, this test involves adding a set of vintage variables for each of the years represented by the time dummies, as well as a set of age variables representing the number of years a product has been available. An F-test is used to compare the unrestricted model, which contains both the vintage and age variables, to a restricted model with just the age variables. The restricted model passes the F-test at the 5% confidence level. Similarly, a test of the restricted (basic) model shown in Table 5 versus an unrestricted model with age dummies also passes he F-test at the 5% level. Passing these specification tests suggests that the choice of hedonic feature variables captures the bulk of the quality differences among products.

Table A1: Full Unrestricted Model with Vintage and Age Dummies

VARIABLE	COEFFICIENT	T-STAT	2-TAIL SIG
C	85.507900	2.0244016	0.047
CELLINKF	83.795536	2.3549361	0.022
EMBEDCHT	110.48591	2.5430191	0.013
BASESHAR	5.5592027	4.8970929	0.000
LOT_MENU	140.63109	5.1525695	0.000
SORT_COL	137.94152	4.1175980	0.000
WYSIWYG	72.660971	2.0899615	0.041
T88	57.853664	0.9567412	0.342
T89	144.87270	1.3700469	0.175
T90	150.79060	1.0338913	0.305
T91	221.97662	1.1289487	0.263
T92	331.61141	1.3622892	0.178
V88	-16.130110	-0.2213550	0.826
V89	-172.30163	-1.4954685	0.140
V90	-173.10073	-1.1052921	0.273
V91	-348.31172	-1.6833796	0.097
V92	-511.67815	-1.9268670	0.058
A1	-57.696159	-1.1244750	0.265
A2	-153.84468	-1.5866877	0.117
A3	-182.39566	-1.2540537	0.214
A4	-140.16999	-0.7990618	0.427
A5	-207.96649	-1.1933186	0.237
A6	-654.16890	-2.1334166	0.037
N	93		
S.E. of Regression	94.27310		
R^2	0.631491		
Adjusted R^2	0.515674		

F-test of unrestricted vs. restricted (no vintage dummies) model, F value = 1.92 < 2.37, (passes at 5% level)

Table A2: Restricted Model without Vintage Dummies

VARIABLE	COEFFICIENT	T-STAT	2-TAIL SIG
C	106.23830	2.5935062	0.012
CELLINKF	98.716892	2.7740386	0.007
EMBEDCHT	101.93425	2.4943070	0.015
BASESHAR	4.2191400	3.9937756	0.000
LOT_MENU	111.27353	4.3907907	0.000
SORT_COL	101.50866	3.4042531	0.001
WYSIWYG	68.130565	1.9903385	0.051
T88	13.552877	0.3381877	0.736
T89	-5.2428993	-0.1266224	0.900
T90	-46.400682	-1.0307503	0.306
T91	-97.778738	-2.0046567	0.049
T92	-92.463955	-1.6077537	0.113
A1	3.1720556	0.1143989	0.909
A2	3.3387987	0.1037154	0.918
A3	19.177771	0.3416083	0.734
A4	89.980532	1.2578345	0.213
A5	89.213280	1.2336163	0.222
A6	-130.58026	-1.0534052	0.296
N	93		
S.E. of Regression	97.041		
R^2	0.582		
Adjusted R^2	0.487		

F-test of unrestricted (with age dummies) vs. restricted model, F value = .875 < 2.181, (passes at 5% level)

APPENDIX B: Discount Data Results

A separate price data set containing advertised discount (street) prices was collected, which consists of 55 observations. The model was estimated using this data set, giving the results shown in Table B1. These results are quite similar to those reported in Table 5, in terms of the main variables. The main difference is that the constant (intercept) term, which was positive and statistically significantly different from zero in the list price data, is not significant in the discount data.

Table B1: Results of the Hedonic Price Equation Estimation

Discount Price (in 1987 Dollars) is the Dependent Variable

VARIABLE	COEFFICIENT	T-STAT	2-TAIL SIG
C	-0.561	-0.016	0.987
CELLINKF	82.177	3.045	0.004
EMBEDCHT	105.768	2.689	0.010
SORT_COL	84.419	2.669	0.011
WYSIWYG	72.525	2.850	0.007
BASESHAR	3.576	5.375	0.000
LOT_MENU	95.688	4.156	0.000
T88	28.435	0.934	0.356
T89	13.128	0.342	0.734
T90	9.793	0.288	0.775
T91	-39.415	-0.793	0.432
T92	-110.735	-1.721	0.092
N	55		
S.E. of Regression	64.593		
R^2	0.729		
Adjusted R^2	0.660		

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